Sustainable management of Peat Swamp Forest of Sarawak with special reference to Ramin (*Gonystylus bancanus*)

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Sustainable management of Peat Swamp Forest of Sarawak with special reference to Ramin (G*onystylus bancanus*)

Development of a monitoring system

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ABSTRACT

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Peat swamp forests in Sarawak are valuable in terms of timber and biodiversity, but heavily degraded. In order to assess the current status, potential developments and possible management interventions, an adequate monitoring system is necessary. In this study a new monitoring system is proposed, based on an evaluation of the current system combined with the identification of present PSF values. Adjustments include the monitoring of all woody species in all size classes, the monitoring of standing and fallen dead wood and the monitoring of environmental factors such as hydrology and peat depth. Moreover, the protection and monitoring of primary, undisturbed PSF is of paramount importance in the light of conservation of biodiversity and the design and evaluation of management interventions.

Keywords: Peat Swamp Forest, Ramin, monitoring system, growth & yield, biodiversity

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Preface

This report is part of a larger study on Ramin (*Gonystylus bancanus*), one of the main commercial species of the peat swamp forest in Sarawak. The Ramin Project focuses on the silviculture and management of Ramin, including the regeneration, growth and conservation. We would like to thank the staff of the Forest Department of Sarawak for logistics and support and Paul Hilligers for assistance in the setup of the monitoring system and comments on earlier drafts of this report.

Abstract

Peat swamp forests (PSF) in Sarawak are valuable in terms of timber and biodiversity, but heavily degraded. The Ramin Project is aimed at formulating a strategic management plan for sustainable conservation and use of the PSF.

In order to assess the current status, potential developments and possible management interventions, an adequate monitoring system is necessary. In this study a new monitoring system is proposed, based on an evaluation of the current system combined with the identification of present PSF values.

The current system consists of an extensive network of permanent sample plots and is focused on growth and yield. However, present PSF values include biodiversity conservation, rehabilitation of degraded forest and carbon storage. Therefore, adjustments of the monitoring system are advised. These adjustments include the monitoring of all woody species in all size classes, the monitoring of standing and fallen dead wood and the monitoring of environmental factors such as hydrology and peat depth. Moreover, the protection and monitoring of primary, undisturbed PSF is of paramount importance in the light of conservation of biodiversity and the design and evaluation of management interventions.

1 Introduction

Peat swamp forests (PSF) in Sarawak are a valuable source of timber and biodiversity (Lee 1977, 1979, 1982, Anon. 2001). However, at the moment most of the peat swamp forests are degraded by heavy exploitation (Ibrahim & Yusoff 1992, Wong 2002). Ramin (Gonystylus bancanus) is one of the main commercial species of the PSF. The Ramin Project will help to formulate a strategic management plan for the remaining PSF in Sarawak, including silvicultural techniques for its continuous conservation and utilisation. Special emphasis will be placed on the regeneration, growth and conservation of Ramin.

Conservation and sustainable use of the PSF depends on sound management plans and implementation. Information regarding the current status of, and developments in the PSF are therefore indispensable. This information has to be updated regularly, indicating the importance of a monitoring system. Monitoring systems should be aimed to achieve specific objectives with a design and focus on long-term developments.

In this report a brief background on monitoring systems is given and the current monitoring system, as developed by Sarawak Forest Department, is described. Possible objectives are formulated and monitoring aspects identified. Then, the current monitoring system is evaluated, recommendations formulated and a proposed monitoring system described.

1.1 Background of forest monitoring

Forests can only be managed on a sustainable basis if:

- The (economic) value of the forests can be determined
- The disturbance caused by forest utilisation is regulated in such a way that ecosystem productivity is maintained[1]

This can only be achieved if extensive data on the forest (growth) are available. Data can be collected haphazardly or systematically e.g. in Permanent Sample Plots (PSP). The advantage of the latter is that detailed analyses on survival and growth of species and individuals are possible, while from the first approach only more general trends can be deduced. Adequate growth and yield data are essential in achieving and maintaining sustainable forest management. Permanent Sample Plots (PSP) are permanently demarcated areas of forest, typically 1 ha in area, that are periodically re-measured (Alder & Synnott 1992). They provide estimates of changes in forest structure, composition, stocking and volume. Together with other sources of

[1] Cf. Alder & Synnott 1992

information (like inventory data and allometric samples) PSP data provide the input for predictions (models) which ultimately are used to evaluate and adjust forest management.

Information from these PSP's can be used in a variety of ways (Condit 1998); the data provide insight in productivity of valuable species and sustainable harvesting, they can be used to assess carbon storage or species preservation and extinction rates, and changes can be observed to evaluate the effects of climate change and human disturbances.

In the design and implementation of a PSP system, several aspects have to be addressed. Objectives and corresponding parameters have to be formulated,. levels of interested should be identified, and a sampling design constructed. A number of possible topics are mentioned in table 1 and 2.

Table 1: Possible monitoring aspects in PSP

Monitoring items	**Aspects**	**Possible parameters**
Objectives	Growth & yield Biodiversity Carbon storage	Volume and growth of valuable species Number of species, naturalness Biomass
Levels of interest Environment level	 Landscape characteristics Forest characteristics Patch characteristics	 Forest types, catchment area Topography, slope, soil Developmental phases
Tree level	Tree species Tree size & position Tree form Tree condition	Specific or all Dbh, height, co-ordinates Crown (height, form, position), bole height Damage, climber infestation

Table 2: Possible design topics in PSP[2]

Design topics	**Aspects**	**Recommended**[3]
Plot layout	Grid, stratified, random	Two-staged stratified random
Plot shape	Point, circle, rectangle	Rectangle shape
Plot size		1 ha (25 20x20 m quadrats)
Plot subdivision (scale)	Seedling (<1.5 m) Sapling (1.5 m – 5 cm dbh) Pole (5-20 cm dbh) Tree (>20 cm dbh)	Strips Centre quadrat Five centre quadrats All quadrats
Plot number	Area, variation	Minimum of 50 Maximum of 1000 Average 1 plot /1000 ha
Monitoring interval		Every 5 years

In the PSP, often monitored to provide data for growth and yield models, the dbh limit is usually 10 or 20 cm. However, to be able to answer more detailed (research) questions (e.g. on population dynamics, species composition, regeneration etc.), more detailed data have to be collected as well. The type of information, the level of detail and the frequency depend on the questions addressed.

Traditionally, PSPs were designed to evaluate the growth and yield of several commercially interesting tree species. However, more recently other forest functions are receiving increasing attention. These include non-timber forest products, the protection of watershed areas, ecotourism, biodiversity conservation and carbon storage. New questions will be asked in the light of these 'new' functions and a monitoring system will have to be adjusted accordingly.

Ideally, a monitoring system should consist of a series of permanent plots laid out in a systematic network, covering the range of variability of logged and non-logged forests. This will provide insight into the natural structure, composition and dynamics in comparison with silvicultural practices.

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[2] After Alder & Synnott 1992
[3] Alder & Synnott 1992

2 Current monitoring system

The monitoring system aims to assist the silvicultural system with information on present and future stocking. In the silvicultural system treatments were carried out one (G1) and ten years (G10) after logging (Chai 1997a,b). They were designed to increase the growth of the potential crop trees by poison-girdling all trees >20 cm dbh which were defective, deformed and/or damaged or of an undesirable species. G1 was carried out routinely from 1961 till the present. Over the years there have been some adjustments:

- prior to 1973: only 8 desirable species (treatment too intense)
- 1973-1989: inclusion of another 6 desirable species (total 14) and 31 acceptable species
- post 1989: dbh limit from 20 - 30 cm.

G10 was done on a much smaller scale, and not routinely.

2.1 Monitoring

The current monitoring system was designed to gather information on the current status, growth and yield of commercially interesting tree species. A great quantity of data has been collected in logged over PSF since the early 1970s (Chai 1997a,b, Tan 2002). Data were collected at three levels:

1. Diagnostic sampling (DS)
2. Yield Plots (YP)
    - 45 plots, established between 1970-1977, measured 6-8 times, latest measurement 1994-1996
    - 19 plots, established in 1987, measured 4-5 times, latest measurement 1993-1995
3. Research Plots (RP)

Diagnostic sampling
Diagnostic sampling was carried out according to the system of Dawkins & Palmers (1970), with the stocking survey as the primary goal. In DS an assessment of basal area and stocking is conducted in order to determine the competitive status (and possible treatments). In each quadrat the best individual is selected and size class, crown position and impeders are recorded. Also trees >10cm dbh are recorded in 10 cm classes (see Table 3).

Table 3: Diagnostic sampling in logged-over MSF[4]

Year	Location	Area (ha)	
		Forest covered	Sampled
1970	Tatau PF	676	18.2
1971	Sebuyau PF	743	17.1
1973	Loba Kabang PF and 4 other areas	29,800	314.1
1974	Loba Kabang (S) PF, Pulau Bruit PF and 2 other areas	21,048	204.0
1976	Bawan FR, Btg Lassa PF, Loba Kabang (N) FP and Retus PF	5,910	118.3
1979	Btg Lassa PF, Daro FR and Jamoreng PF	10,414	106.2
1982	Kut-Mudan PF, Lepah PF and Saribas FR	10,623	105.9
1983	Bawan FR and Triso PF	8,254	82.6
1986	Btg Lassa PF and Jemoreng PF	6186	60.5

Yield plots

Yield plots are implemented for growth and yield estimates. Usually they are 1 ha in area and cover 0.25% of the total area or consist of 1 plot per 400 ha. The YPs are divided into a hundred 10x10 quadrats.

In time, the PSP monitoring system changed. Before 1983 the best (potential) crop trees (>5cm dbh) were recorded for size, crown position, crown form and competitor status. Other species were also mapped, numbered and identified, but only assigned to a dbh class (in feet) (Tan 2002). Between 1970 and 1977 45 YPs were established in various logged-over MSF and measured (most recently in 1991-1996). In 1987 all trees >10 dbh were identified and their size and crown position recorded. An additional 19 plots were established in 1987. In these detailed measurements were made of the site, the stability, decay-status and degree of lean of the trees and the presence of climbers (see procedure in Hutchinson 1982). The latest measurements were carried out in 1993-1995. In 1987 the older plots were also measured using the same procedures. Table 4 gives information on the plots. The locations of the plots are shown in Appendix 1 and the inventory form in Appendix 2.

[4] After Chai 1997b

Table 4: Yield plots in logged-over MSF[5]

Yield Plot (no. of plots)	**Location**	**Yrs since felling**	**Year establ.**	**Measure-ments**		**Condition**
				No.	Latest	
01(1)	Pulau Bruit PF	43	1971	6	1997	encroached
02-03 (2)	Naman FR	39	1971	7	1996	
07-10 (4)	Simunjan FR	33-36	1972	7	1998	6,7,8 affected
11-12 (2)	Sedilu FR	35-36	1972	8	1994	converted
13-16 (4)	Triso PF	33-38	1973	8	1999	encroached
17-18 (2)	Sebuyau PF	30-37	1973	8	1994	converted
19-22 (4)	Saribas FR	38-39	1973	8	1999	affected
23-26 (4)	Daro FR	32-33	1973	8	2000	24,26 encroached
27-29 (3)	Tatau PF	24-25	1973	8	1999	27,29 affected
30-36 (7)	Btg Lassa PF	27-29	1976	6	2000	
37-42 (6)	Loba Kabang PF	35-38	1976	8	2000	(to be) affected
43-48 (6)	Bawan FR	30-34	1976	6	2001	(to be) affected
65-72 (8)	Bawan FR	20-27	1987	6	1995	
73-78 (6)	Btg Lassa PF	27-32	1987	5	2001	
79-83 (5)	Retus PF	29-35	1987	4	1998	

Research plots

Research plots are permanent sample plots one or more ha in size. They are measured with the aim of studying the development of logged-over forest with or without silvicultural treatment. This will provide better insights into the growing stock and crop performance, recruitment, growth and mortality and silvicultural practices.

At present three RPs are active (RP 43, 44 and 52). Chai (1997b) provides an overview of active and inactive research plots. In the RPs data are gathered at tree, sapling and seedling levels. Information on trees >10 dbh is gathered in 10x10m quadrats. Saplings (2.5-10 cm dbh) are measured in 5x5m subplots within the quadrats. Information on seedlings (30 cm height - 2.5 cm dbh) comes from one quarter of the sapling subplots. In the quadrat forest class, stem identity class, silvicultural treatment of individual trees, dbh, height, crown (form, position), injury and decay to root, stem and crown and woody climbers are measured.

[5] After Tan 2002

Table 5: Research in MSF[6]

Investi-gation	Description	RP No. (date establ.)	Forest area
5	Effects on the regeneration of desirable species of 4 poisoning treatments in MSF 10 yrs after logging	43, 44 (1961)	Pulau Bruit PF, Naman FR
13	Effect on the regeneration of desirable species of 6 poisoning treatments in heavily felled MSF immediately after logging	52 (1969)	Loba Kabang (S) PF

2.2 Data analyses

As can be seen above and in Chai's (1997b) overview, a wealth of information has been gathered on forest structure, composition and development in logged-over forest. However, the detailed inventories before 1987 concentrated on a small number of species and the data are not fully digitised and so are difficult to analyse and compare with the more detailed recent measurements (Tan pers. com.). Moreover, illegal logging affected some of the monitoring plots and re-logging was (often) performed outside the monitoring plots. This, together with a dbh limit of 10 cm (excluding seedlings and saplings) may hamper detailed analyses (Tan pers. com.).

Nevertheless, the data have only partly been analysed and probably contain detailed information which may help to address (*inter alia*) the *ramin* regeneration issue. Hamzah and others (Hamzah *et al.* 1998) made a start and used three yield plots to do an additional study into the effects of the logging treatment on *ramin* regeneration. The focus of that study was mainly on regeneration, observed over a three year period (1996-1998), and its relation to stand history and current status. In the present *Ramin* Project, one of the main issues is *ramin* regeneration.

2.3 Evaluation

Within the PSF, Mixed Swamp Forest (MSF), *Alan Bunga* and *Alan Batu* forest types have (potentially) commercially valuable tree species and most of these areas have been logged over in the past. Possibly only the *Padang Alan* forest, consisting of few commercial timber species, remains relatively undisturbed. According to Wong (2002) almost all PSF has been disturbed, with possibly only 1.5% classified as natural forested original peat swamp forest (however, ground verification is necessary; Wong pers. comm.). Relatively undisturbed primary PSF can give valuable information and is thus of paramount importance.

[6] After Chai 1997b

At the moment there is an extensive system of YPs, although a number of these are affected by illegal activities. The protection of these plots is essential for reliable growth and yield estimates. Furthermore, control plots (with no new silvicultural interventions) in close proximity to YPs should be established in undisturbed PSF in order to enhance insights into the effects of the silvicultural system on growth and yield.

The current monitoring system is primarily focused on growth and yield estimates. Inventories before 1987 focused on a limited number of commercially interesting tree species and the lower dbh limit (10cm) excludes seedlings and saplings, critical phases in the growth cycle. Moreover, monitoring data are not always readily available. These factors hamper long term growth and yield analyses. However, the data collected contain valuable information not yet fully analysed.

3 Objectives of a new monitoring system

The aim of this study is to formulate a new monitoring system. Monitoring can be carried out for:

- growth and yield predictions
- regeneration/rehabilitation potential
- biodiversity assessments
- carbon storage

The main reasons behind the current systems of YPs are the first two reasons above, while the second two are possible additional reasons.

3.1 Growth and yield

The current monitoring system aims to provide information on growth and yield. Monitoring approaches will have to be formulated depending on the level of detail desired (ranging from stand models to distance-dependent tree models). In the case of distance-dependent tree models all tree positions, as well as their sizes and identities, are monitored. Moreover, the presently measured dbh limit of 10 cm reflects only a part of the whole growth cycle.

In order for an adequate insight into the growth and yield of commercially interesting tree species in PSF, regular measurements of all species in all size classes are essential. Adequate predictions should be possible if such measurements are taken together with the competitive status and crown and stem form parameters.

3.2 Rehabilitation

To be able to monitor the regeneration and rehabilitation of PSF forest types, the current monitoring system has to be adjusted. Preferably, information is needed on both disturbed and undisturbed forest. Species occurrences have to be analysed over the whole size-range. Information on phenology, seed dispersal, storage, germination and seedling development is needed in order to evaluate and manage rehabilitation processes. In addition to these 'response variables', changes in environmental factors should be monitored in order to be able to evaluate the rehabilitation potential (which will also affect growth and yield, biodiversity and carbon storage).

By measuring all individuals, positions and growth, the forest condition and regeneration capacity can be assessed. Further important aspects, such as phenology and seed dispersal and predation, are possibly more easily studied in separate projects. Including undisturbed PSF plots in the monitoring system is extremely valuable in the light of this and the other objectives. Moreover, for an adequate assessment of change and potential rehabilitation, monitoring of water tables and peat depth should be considered.

3.3 Biodiversity

Biodiversity is often studied in the light of increased human activities. Such activities may result in the number of species declining, remaining at status quo or increasing. Nevertheless, abundances and composition may change. Biodiversity encompasses several hierarchical levels (landscape, ecosystem, species and genetic levels) and three aspects (composition, structure and process (Noss 1990, Franklin 1988)). In addition, specific management aims can be recognised (these may include forest naturalness (integrity), specific (endangered) species or species diversity). In order to monitor biodiversity management aims need to be carefully formulated and the parameters monitored adjusted accordingly. In general, tree and non-tree floristic diversity can be monitored but faunal aspects are often more difficult and time-consuming to monitor. Since it is not possible to monitor all species, indicator or key species can be used to represent a broader species group (although a strong scientific basis for this is still lacking). Indicator species come preferably from different biological groups (birds, mammals, insects; e.g. Stork 1995). However, detailed knowledge is needed to select possible species (groups). Moreover, species groups may react differently to various levels of disturbance, as indicated by Lawton *et al.* (1998).

Forest structure can also be used as a basis for diversity assessments. Specific structural characteristics can be representative for the occurrence of specific species (if species habitat preferences are known). The structure defines the three-dimensional habitat on which species depend. Structural diversity can therefore possibly be regarded as an indication of potential species diversity. Furthermore, certain structural characteristics can be indicative for forest change (Koop *et al.* 1995).

Possible (floristic) parameters to be monitored could be:

- *Structure*
  position, dbh (big trees, distribution), height, basal area, density, gaps, layering, crown shape, tree stumps
- *Species composition*
  species composition and abundance
  disturbance indicators (pioneer/climax species, exotic species)
  atmospheric moisture indicators (epiphytic ferns, mosses)
- *Process/function*
  dead wood (standing, lying, pits and mounds), regeneration, extinction

Ideally, both undisturbed and disturbed forest should be monitored to assess undisturbed structure, composition and dynamics and to evaluate the effects and magnitude of disturbance on diversity. Nevertheless, even without a 'baseline' diversity assessment, the above-mentioned parameters can be indicative of diversity and disturbance.

In peat swamp forests the level of interest is at the ecosystem level. In this project and within the framework of the PSP system, the general focus is on the abundance and composition of the flora, as in most long-term monitoring studies. Other organisms are equally important but considered too complicated to monitor within the current framework. Several aspects of biodiversity could be studied (composition, structure and processes) to acquire a solid insight into species richness, habitat diversity, disturbance levels and dynamics in space and time. If necessary, specific indicator species can be identified and habitat requirements described. These habitat requirements can possibly be translated into forest structure, composition and dynamics, enabling assessment of the potential suitability of the PSF for the species in question. However, this is beyond the focus of the current system. It is agreed that a focus on all plants (dbh >1cm), with size and positions measured, enables assessment of the floristic diversity and structural complexity.

3.4 Carbon storage

The carbon stock of forests is becoming increasingly important in the light of global environmental issues. PSF forest may play an important role. An assessment of the amounts stored and the dynamics is therefore very valuable and may assist policy planners in assessing the importance of PSF.

In order to assess the importance of PSF for carbon storage, the biomass and composition of all living and dead plant parts (both above and below ground) should be measured. However, in a monitoring system the main practical aspect measured is plant abundance and size and changes therein over time. Detailed conversions (e.g. from dbh to biomass and of individuals to woody and non-woody plant parts) can possibly be based on existing conversion equations or separate studies. Nevertheless, the amount and dynamics of biomass in dead wood is, in this light, an important aspect (as it is for biodiversity), and should preferably be included. The role of peat as a sink should be investigated in other studies.

3.5 Recommendations

The current system and new reasons for monitoring are compared in Table 6. The (possible) specifics of each reason for monitoring are highlighted and (possible) adjustments to the current system are indicated.

Table 6: Recommended monitoring aspects for the various objectives

Reason for Monitoring	**Requirements of PSP system / Adjustments to existing system of YPs or RPs.**
Growth & yield prediction	Depending on the modelling approach (whole stand, size class or individual tree, either distance dependent or distance independent), and the functions developed for the model, the parameters to be measured will vary. Adjustments: Little adjustment needed. Measurements could include size, identity and competitive status of individuals (trees, saplings, seedlings).
Regeneration/ rehabilitation potential	Assessment of forest condition and rehabilitation potential requires insight into canopy coverage, competitive status (e.g. size (dbh, height), crown position, crown form), shade tolerance, phenology, seed dispersal etc. Adjustments: Assess canopy coverage, competitive status and regeneration and environmental factors (e.g. water table and peat depth).
Biodiversity assessment	Ideally this would require assessments at least at the species level for both flora and fauna. Flora is easier to assess. Fauna is more difficult and possibly only feasible if focus is given to certain indicator species (e.g. birds and mammals) or key (endemic, threatened) species or functional groups. Forest structure can be used as an important indicator. Adjustments: Floristic composition, forest structure (identity and size of all individuals, possibly position or relative position, amount of dead wood).
Carbon stock	This requires some means of estimating at least the above-ground biomass (trees, understorey vegetation), necromass (litter) or the below-ground organic matter or carbon (roots and soils). Tree allometry equations for estimating carbon stock, if not available, may have to be developed. Understorey vegetation, litter and soil may have to be destructively sampled. The regular measurements required may be tedious and costly. Adjustments As suggested above.

4 Proposed monitoring system

The draft monitoring system here proposed is partly based on various (extensive) research and monitoring studies (Hutchinson 1982, Alder & Synnott 1992, Korsgaard 1992, Vanclay 1994, Koop *et al.* 1995, Dallmeier & Comiskey 1996, Chai 1997a,b, Condit 1995,1998, Alder, Oavika & Yosi 1999, Daamen 1999, Daamen & Dirkse 2001a,b, Clerkx & van Hees 2002, Philips *et al.* 2002 and Tan 2002). The theoretical considerations and practices in other studies have to be adjusted to local environmental, social, organisational and economic circumstances. Therefore, the expertise of, and discussions with, the staff of Sarawak Forest Department (F. Chai, S. Tan, M. Mohizah, D. Liam, J. Wong) were of paramount importance for the joint design of a solid and feasible draft monitoring proposal.

4.1 Monitoring objectives

It is generally agreed that a monitoring system should be solid and focussed on long-term developments, addressing the main objectives. Specific topics are often more easily studied in specific experiments or within a short time-frame (the monitoring plots could be very valuable for this (destructive studies excluded)) and combinations of long-term monitoring and short-term studies should be encouraged. As already discussed, the main aims of a monitoring system are growth and yield predictions, regeneration/rehabilitation potential, biodiversity assessment and carbon storage assessment.

4.2 Area to be studied

As indicated by Wong (2002) the extent and continued existence of PSF are under pressure. Most PSFs are (severely) disturbed and large areas are being converted to oil palm plantations. The (possibly) few areas of undisturbed primary PSFs are therefore of paramount importance for conservation and for assessment of the various values and functions of PSF. Information on structure, composition and dynamics of primary PSF (if available) would be very valuable in assessing the potential of PSF for growth and yield, biodiversity, carbon stock, management interventions, water retention etc. in relation to disturbed PSFs. Therefore, a monitoring system should preferably include all levels of disturbance.

The current YPs offer valuable information on past and present structure, composition and dynamics (at various levels of detail). Continuation of these plots should therefore be advised. However, as indicated by Tan (2002) several YPs are no longer useful. Furthermore, as can be concluded by the ongoing logging and concessions in PSF, several PSF areas will be converted in the future to other land uses, with the possible loss of more YPs. To assure the existence of a long-term monitoring system to address the critical issues stated above, we propose that a pilot monitoring PSP network be started in Maludam National Park, which is a protected area. This will also be feasible in the time-frame of the *Ramin* Project. However, it is strongly recommended that the remaining YPs in the other areas in the monitoring network be included as these plots encompass various levels of (ongoing) disturbance and different environmental characteristics.

Pilot area and plot layout
The pilot area is the Maludam National Park. It consists of four main PSF types; mixed swamp forest (MSF), *Alan Bunga* (ABU), *Alan Batu* (ABA) and *Padang Alan* (PAL) (Anderson 1961). Although the MSF has the highest potential for commercial exploitation, other forest types also have been logged. Furthermore, the various forest types are important in terms of biodiversity, carbon stock, etc. It is therefore proposed that the entire area of Maludam NP be included in the PSP system. Stratification should preferably be based on independent abiotic variables such as water table, peat depth and composition, soil type etc. However, at the moment no detailed information is available. Thus it is proposed to stratify the monitoring plots according to the four forest types, based on the map of Anderson (1961, see Appendix 3).

Stratification
Plots should ideally cover the whole range of forest types. They can be placed at random, to prevent human bias and facilitate statistical analyses. However, growth and yield, biodiversity, carbon stock etc. may vary due to local differences in abiotic environment. The 'extremes', both on the low and high side, are possibly less common and thus possibly not encountered in a complete random census. Nevertheless, these 'extremes' are very useful in assessing the above-mentioned aspects. It is therefore suggested that the forest be stratified according to type and plots be placed randomly in each type.

Disturbance gradient
The Maludam area consists of the former Triso Protected Forest area and former Maludam Forest Reserve area. Each has a different history of disturbance (Tan pers. comm.) and thus different current forest structure and composition. Moreover, differences in logging history, logging date and intensity exist <u>within</u> each of the two (Triso and Maludam) regions, creating a disturbance gradient within each forest type. It would be worthwhile to study a logging-time gradient but after careful consideration it was concluded that this required a detailed study of logging history. Since logging intensity, number of harvests and treatments and number of species extracted varied from place to place, depending *inter alia* on local conditions, concessionaire and market conditions at the time of logging, a very complex disturbance mosaic has been created.

Link with remote sensing
Continuation of monitoring of existing YPs is highly recommended and four YPs are already located in the Triso area MSF. In order to combine results of this monitoring study with the remote sensing study (which is less detailed but covers a larger area (Wong 2002)) we also propose to include one plot in an area covered by IKONOS

satellite imagery. In this way we enhance the possibility of ground validation for remote sensing and the possibility for extrapolation of the results of the monitoring study. The remaining plots should be randomly distributed equally in the former Triso and Maludam areas.

Plot size and number

In order to be able to compare past, present and future measurements and other studies, it is advised that the 1 ha plot size of the YPs and RPs (100x100m) is maintained. Plots should be homogenous (soil/peat type and parent material) and accessible but sufficiently secure from human disturbance (Philips *et al.* 2002).

The number of plots depends on the variability of forest types and human and financial resources. PSF has a lower diversity and is more uniform in structure and composition than lowland rainforest. Although one would expect its variability to be lower no actual data are available at the moment. The current PSP system comprises 70-80 plots (Tan 2002) of which a number have already been terminated and/or affected by oil palm plantations. The loss of a number of old YPs could be balanced by addition of new plots in Maludam N.P. In the context of the *Ramin* Project, the human and financial resources are limited to the extent that an estimated 25 plots can be established and measured in 2002 and 2003 (five can be done in 2002). After considering the area of the different forest types, the potential value and limiting resources, the following options have been formulated (Table 7).

Table 7: Possible number of plots per forest type

Forest type	Option 1	Option 2	Option 3	Option 4	2002
MSF	10	14	12	13	1-2
Alan Bunga (ABU)	5	5	6	5	1
Alan Batu (ABA)	5	4	5	5	1
Padang Alan (PAL)	5	2	2	2	1
Primary					1

Since the former Triso and Maludam areas differ, the numbers of plots suggested for each forest type (in the former Triso and Maludam areas respectively) are as follows: MSF 6;7, ABU 3;2, ABA 2;3, PAL 1;1

4.3 Plot sampling

The 1 ha plot will be divided in 100 10x10m subplots. Sampling will be conducted on different plant categories: trees >10 cm dbh, saplings 1-10cm dbh and seedlings 0.3 m height – 1 cm dbh. Trees will be sampled in all 10x10m subplots. Saplings will be sampled in 40% (randomly allocated) of the 100 subplots, with a 10 m buffer at the outer perimeter. Seedlings will be sampled in all the sapling subplots but in a randomly allocated area making up one quarter (5x5 m) of each plot. Plots and subplots will be permanently marked and existing vegetation should not be damaged (line-cutting is proscribed). The figure of 40% is an expert estimate, based on data from the Lambir permanent plot, in which 60% was concluded to be adequate (Tan pers. comm.). The PSF types are considered to be less complex than Lambir.

4.4 Measurements

Plot characteristics

Plot characteristics to be recorded include location, local topography, hydrological aspects (water level), peat depth, disturbances, silvicultural treatments, (former) rail tracks etc. with the exact procedures for peat depth and water table assessment worked out by experts from Sarawak Forest Department.

In general, trees (individuals) and stems (next to area level, plot level, etc.) are recognised. Some items are individual-specific (e.g. species); other items are stem specific (e.g. dbh, height). Actual densities, volumes and basal areas etc. can be calculated for each living and dead, standing, hanging and lying piece of wood, although not all variables will be recorded on all woody life forms. Different variables are coupled with different hierarchical levels (in the field and in the database). Basically, the system can be based on the hierarchy shown in Table 8. We suggest that every individual (with its own rooting system) be numbered with a unique, consecutive number.

Table 8: Specific aspects for individuals (life form/type and parameters) and stems (parameters)

Woody individuals

Life form size / type	**Woody individual parameter**					
	Item	**Crown form**	**Crown illum.**	**Climbers**	***Ficus***	**Coppice**
tree	xy	compl. circle	emergent	no	no	no
sapling	species	irreg. circle	full overhead	harmless trunk	trunk	old
seedling	crown radii	half circle	some overhead	harmless crown	crown	new
	crown depth	less then half	side light	harmless both	both	
tree(let)	crown cover	few branches	no direct light	harmful trunk		
climber	point of measurement (change)	coppiced		harmful crown		
palm	(climb 1st tree)	no crown		harmful both		
crown parameters						

Stems (pieces)

Stem (piece) parameter						
Item	**Status**	**Condit-ion**	**Damage**	**Growth**	**Decay**	**Log grade**
dbh	living	standing	complete	meristem intact	sound	commerc.
height	dead	hanging	broken	merist. no replacement	part rotten	deformed
(diam. at mid-point)	missing	fallen	cut	meristem replacement	rotten	damaged
coordinates (top)					decomp.	
coordinates bottom)						

Seedlings (0.3 m high to 1 cm dbh)

- all individuals in a quarter of the sapling subplots (5x5 m sub-subplots)
- tagging with unique number
- mapping
- dbh measurement
- height measurement
- species identification
- plant status, condition, damage

Sapling (1-10 cm dbh)

- all individuals in 40% of the 10x10m subplots
- tagging with unique number
- mapping to 10 cm coordinates
- dbh measurement
- height measurement
- species identification
- plant status, condition, damage

Trees (>10 cm dbh)

- all individuals in all 100 10x10m subplots
- tagging with unique number
- mapping to10 cm coordinates
- dbh measurement
- height measurement
- species identification
- crown position
- crown form
- crown size
- log grade
- plant status, condition, damage
- decay

Climbers

- all individuals, according to size limits stated above
- tagging with unique number
- mapping (>1cm dbh)
- dbh (>1 cm dbh)
- record 1st host tree (number) in which it occurs

Dead wood (>10 cm base)

- record if standing/fallen
- record snapped/uprooted
- diameter at middle
- if lying, location of top and bottom
- decay phase (see Table 8)

Interval
It is suggested that the plots be measured at 5 year intervals. The short-term dynamics can be assessed once, if necessary (in the case of detailed seedling dynamics) within three years.

4.5 Procedures and organisation

Plot size, number, frequency and items measured and recorded depend on financial and human resources. It is important to note that it is more important to have a robust, reliable plot-network with few plots than many inadequately managed plots (Vanclay 1994). Procedures for plot establishment, and permanently marked plots and subplots should follow that described by Condit (1998) and include measurement of individuals, multi-stemmed individuals, buttressed trees, leaning trees etc. Detailed procedures for plot establishment and field measurements and methods for data storage and retrieval will be described.

4.6 Follow up and further recommendations

The PSF and the system for monitoring it depend chiefly on the increased insight provided by the data collected. Attention should be paid to analyses and reporting (in both national and international journals) of the PSF's composition, structure and functioning in relation to past and present disturbance, from the perspectives of the identified objectives (growth & yield, biodiversity, rehabilitation, carbon storage). Tests and procedures have to be established to analyse the various functions and objectives.

The protection of primary PSF is of paramount importance. Monitoring primary PSF will have a three-fold advantage: (1) a reference data-set will be established (2) the opportunity to study in detail the effects of PSF disturbance will continue and (3) the monitoring plots may enhance the chances of conservation of primary PSF.

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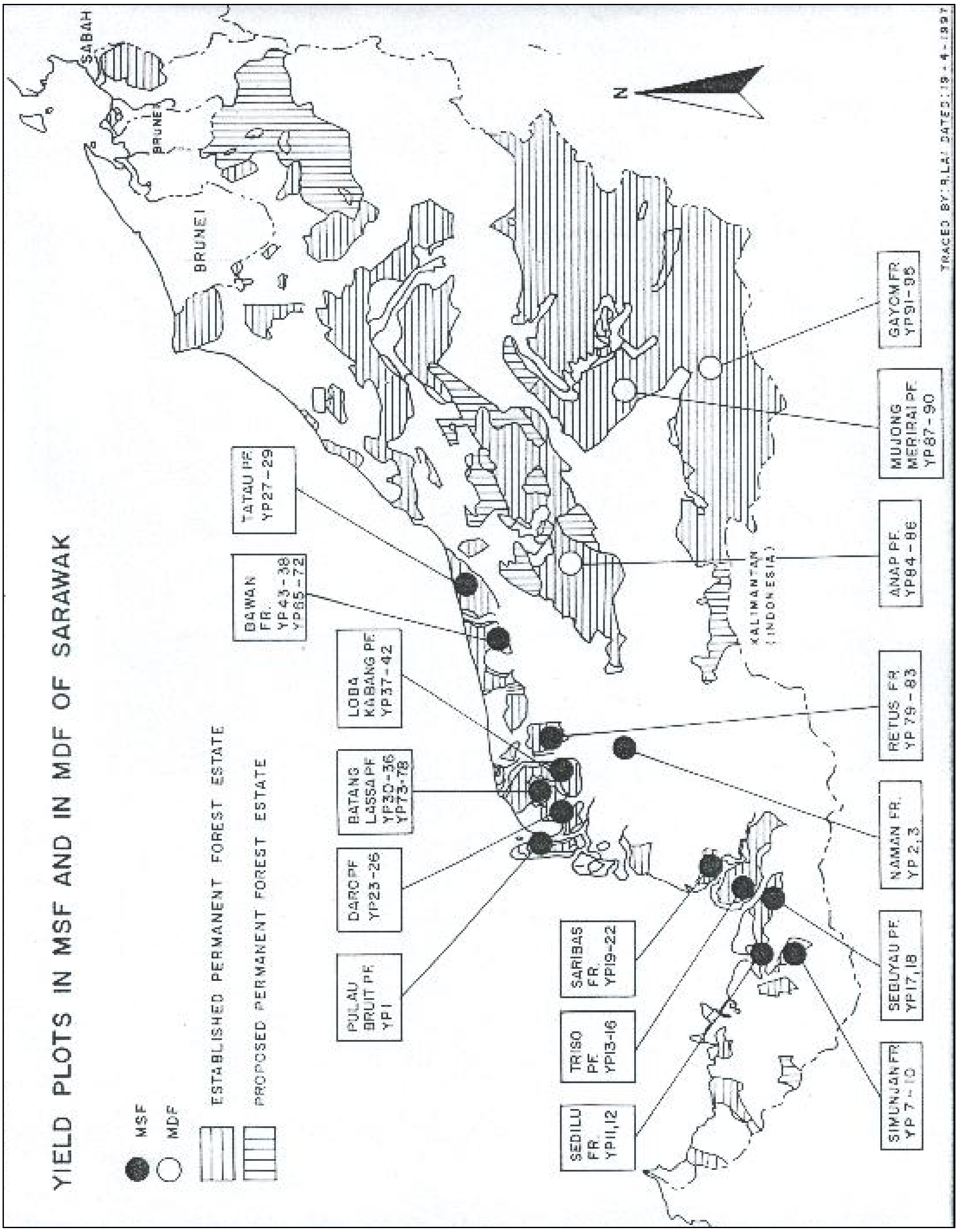
Appendix 1[7] Location of yield plots



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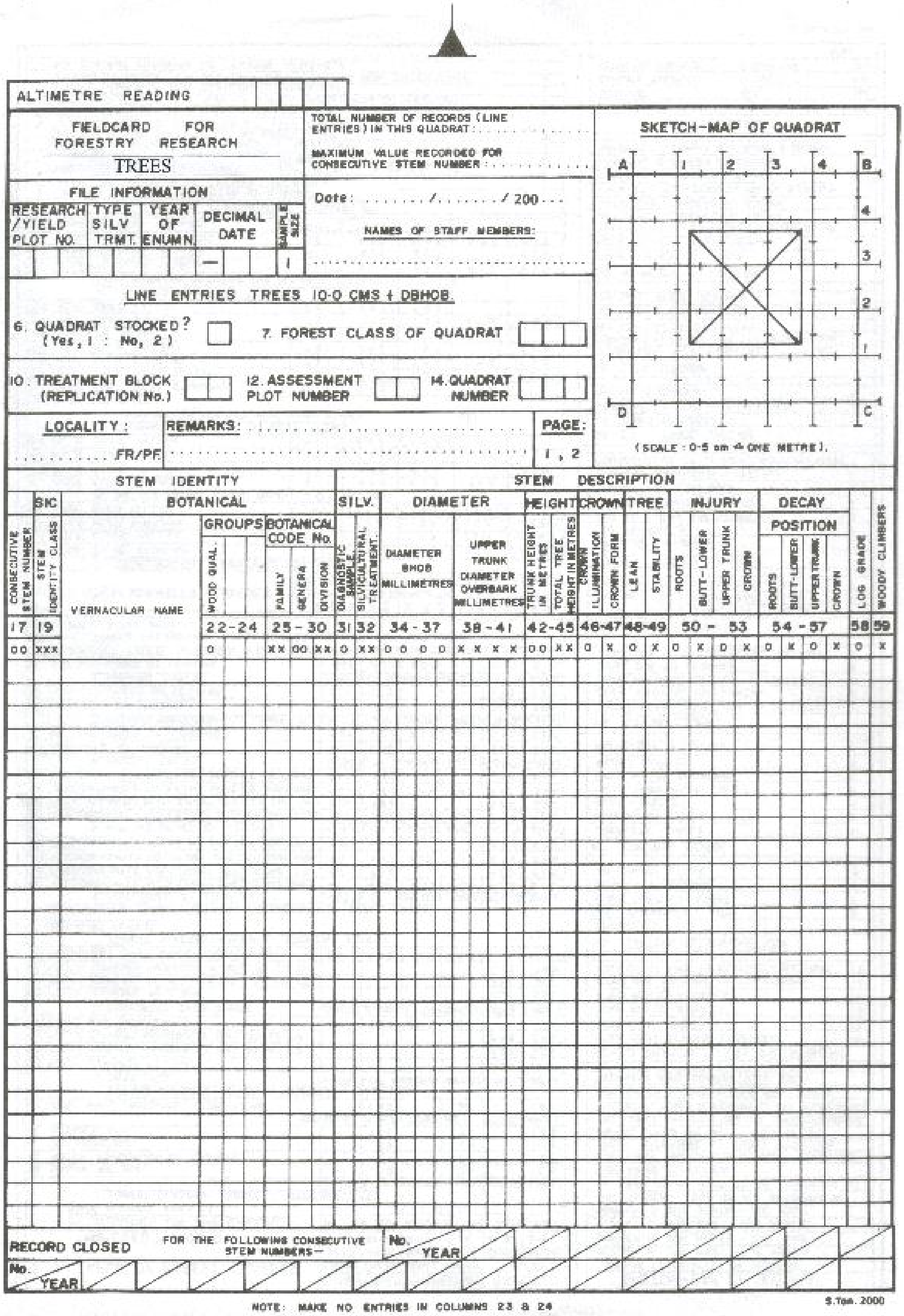
[7] After Chai 1997b

Appendix 2 Current Yield Plot Assessment Inventory Form



ALTIMETRE READING

FIELDCARD FOR FORESTRY RESEARCH

TREES

TOTAL NUMBER OF RECORDS (LINE ENTRIES) IN THIS QUADRAT: . . . .

MAXIMUM VALUE RECORDED FOR CONSECUTIVE STEM NUMBER: . . . .

SKETCH-MAP OF QUADRAT

FILE INFORMATION

RESEARCH /YIELD PLOT NO.	TYPE SILV TRMT.	YEAR OF ENUMN.	DECIMAL DATE	SAMPLE SIZE
			—	1

Date: . . . . / . . . . / 200 . . .

NAMES OF STAFF MEMBERS:

. . . .

LINE ENTRIES TREES 10·0 CMS + DBHOB.

6. QUADRAT STOCKED? (Yes, 1 : No, 2)

7. FOREST CLASS OF QUADRAT

10. TREATMENT BLOCK (REPLICATION No.)

12. ASSESSMENT PLOT NUMBER

14. QUADRAT NUMBER

LOCALITY: . . . . FR/PF

REMARKS: . . . .

PAGE: 1, 2

A 1 2 3 4 B 4 3 2 1 C D

(SCALE: 0·5 cm ≙ ONE METRE).

STEM IDENTITY									STEM DESCRIPTION																		
	SIC	BOTANICAL							SILV.		DIAMETER		HEIGHT		CROWN		TREE		INJURY				DECAY POSITION					
			GROUPS		BOTANICAL CODE No.																							
CONSECUTIVE STEM NUMBER	STEM IDENTITY CLASS	VERNACULAR NAME	WOOD QUAL.		FAMILY	GENERA	DIVISION	DIAGNOSTIC SAMPLE	SILVICULTURAL TREATMENT	DIAMETER BHOB MILLIMETRES	UPPER TRUNK DIAMETER OVERBARK MILLIMETRES	TRUNK HEIGHT IN METRES	TOTAL TREE HEIGHT IN METRES	CROWN ILLUMINATION	CROWN FORM	LEAN	STABILITY	ROOTS	BUTT-LOWER	UPPER TRUNK	CROWN	ROOTS	BUTT-LOWER	UPPER TRUNK	CROWN	LOG GRADE	WOODY CLIMBERS
17	19		22-24		25 - 30			31	32	34 - 37	38 - 41	42-45		46-47		48-49		50 - 53				54 - 57				58	59
00	XXX		0		XX	00	XX	0	XX	0 0 0 0	X X X X	00	XX	0	X	0	X	0	X	0	X	0	X	0	X	0	X

RECORD CLOSED FOR THE FOLLOWING CONSECUTIVE STEM NUMBERS—

No. YEAR

NOTE: MAKE NO ENTRIES IN COLUMNS 23 & 24

S.Tan. 2000

7-9. TABLE OF FOREST CLASSES. "IMPEDED" (ADD 10)	DOM/OVERTOPPED BY LARGE TREES GOOD SITE	DOM/OVERTOPPED BY LARGE TREES POOR SITE	DOM/OVERTOPPED BY SMALL TREES GOOD SITE	DOM/OVERTOPPED BY SMALL TREES POOR SITE	EXPOSED TO LIGHT GOOD SITE	EXPOSED TO LIGHT POOR SITE
BOUNDARIES ON THE GROUND	IN THE AIR ABOVE THE QUADRAT					
50 % QUADRAT AREA IS:						
1. FOREST CLASSES – GROUP I. UNPRODUCTIVE.	(1–100 % OF QUADRAT AREA)				(100 % AREA)	
10. SWAMP, NATURAL.		102		104		106
12. WATER IMPOUNDED BY LOGGING.		122		124		126
14. WATERCOURSE		142		144		146
16. STERILE SITE.		162		164		166
	(VARIABLE CANOPY OPENING)				(100 % AREA)	
18. OPEN SPACE, NATURAL, LONG-TERM.		182		184		186
FOREST CLASSES – GROUP II, TEMPORARY OPENINGS. 2. BARE SOIL.	(1–100 % OF QUADRAT AREA)				(100 % AREA)	
20. FULLY EXPOSED TO LIGHT					205	206
22. FULLY EXPOSED MARGINALLY INFL. BY SM. TR.					225	226
24. FULLY EXPOSED MARGINALLY INFL. BY LG. TR.					245	246
26. BARE SOIL OVERTOPPED	261	262	263	264		
3. TEMPORARY OPEN SPACE.	(VARIABLE CANOPY OPENINGS)				(100 % AREA).	
30. FULLY EXPOSED TO LIGHT.					305	306
32. FULLY EXPOSED MARGINALLY INFL. BY SM. TR.					325	326
34. FULLY EXPOSED MARGINALLY INFL. BY LG. TR.					345	346
36. TEMPORARY OPEN SPACE OVERTOPPED	361	362	363	364		
FOREST CLASSES – GROUP III. STANDING FOREST.						
IMMATURE FOREST.						
REGENERATING FOREST: RESIDUAL PREDOMINANTLY SMALL TREES.						
4. DISTURBED BY LOGGING	(<50 % OF QUADRAT AREA)				(100 % AREA)	
40. PREDOMINANTLY INTOLERANT SPECIES SAPLINGS.	401	402	403	404	405	406
42. PREDOMINANTLY INTOLERANT SPECIES SM. TR.	421	422			425	426
44. PREDOMINANTLY TOLERANT SPECIES SAPLINGS.	441	442	443	444	445	446
46. PREDOMINANTLY TOLERANT SPECIES SM. TR	461	462			465	466
5. NOT DISTURBED BY LOGGING	(< 50 % OF QUADRAT AREA)				(100 % AREA)	
50. PREDOMINANTLY INTOLERANT SPECIES SAPLINGS.	501	502	503	504	505	506
52. PREDOMINANTLY INTOLERANT SPECIES SM. TR.	521	522			525	526
54. PREDOMINANTLY TOLERANT SPECIES SAPLINGS.	541	542	543	544	545	546
56. PREDOMINANTLY TOLERANT SPECIES SM. TREES	561	562			565	566
6. MOSTLY PALMS.	(< 50 % OF QUADRAT AREA)				(100 % AREA)	
60 DISTURBED BY LOGGING	601	602	603	604	605	606
62. NOT DISTURBED BY LOGGING	621	622	623	624	625	626
7. RESIDUAL PREDOMINANTLY LARGE TREES	(<50 % OF QUADRAT AREA)				(100 % AREA)	
70. DISTURBED BY LOGGING	701	702			705	706
72. NOT DISTURBED BY LOGGING	721	722			725	726
8. MATURE FOREST	(<50 % OF QUADRAT AREA)				(100 % AREA)	
80. NOT DISTURBED BY LOGGING	801	802	803	804	805	806

INTOLERANT TREE SPECIES (LIGHT-DEMANDING PIONEER OR SECONDARY SPECIES).
BENUAH, ENTIMAU, KELAMPAYAN, LEGAI, MARKUBONG, MATA IKAN, MENARONG, MENYAM, SABA BUBU, SABAL BESI.

19-21. STEM IDENTITY CLASSES	X X 1 COMPL. TRUNK	X X 2 BROKEN STEM	X X 3 BROKEN STUMP	X X 4 CUT STUMP	X X 9 NOT FOUND
1. TREE SPECIES. STEMS 10·0+ CMS. DBHOB.					
1·1 TREE ALIVE, STANDING	111	112	113	114	119
1·2 TREE ALIVE, FALLEN	121	122	123	124	129
1·3 TREE DEAD, STANDING	131	132	133	134	139
1·4 TREE DEAD, FALLEN	141	142	143	144	
4. MATURE PALMS (TOTAL HEIGHT 2·0+ METRES.					
4·1 PALM ALIVE, STANDING	411	412	413	414	419
4·2 PALM ALIVE, FALLEN	421	422	423		429
4·3 PALM DEAD, STANDING	431	432	433	434	439
4·4 PALM DEAD, FALLEN	441	442	443		
7. CROWNED PARASITES ON DEAD STEMS. (CODE NUMBERS DESCRIBE HOST STEM).					
A. PARASITE ALIVE:					
7·1 HOST TREE DEAD STANDING	711	712	713	714	719
7·2 HOST TREE DEAD FALLEN	721	722	723		729
7·3 HOST PALM STANDING	731	732	733	734	739
7·4 HOST PALM FALLEN	741	742	743		749
B. PARASITE DEAD:					
7·5 HOST DEAD STANDING	751	752	753	754	759
7·6 HOST DEAD FALLEN	761	762	763		
8. CROWNED PARASITES STANDING ALONE (CODE NUMBERS DESCRIBE THE PARASITE ITSELF)					
8·1 PARASITE ALIVE STANDING	811	812	813	814	819
8·2 PARASITE ALIVE FALLEN	821	822	823		829
8·3 PARASITE DEAD STANDING	831	832	833	834	839
8·4 PARASITE DEAD FALLEN	841	842	843		

31. DIAGNOSTIC SAMPLE	
A. LEADING DESIRABLE SELECTED IN QUADRAT	
TREES NOT SELECTED AS LEADING DESIRABLE	0
CROWN ILLUMINATION TREE LD "EMERGENT" OR "FULL OVERHEAD LIGHT"	2
CROWN ILLUMINATION TREE LD SOME OVERHEAD LIGHT	3
CROWN ILLUMINATION TREE LD MOSTLY SIDELIGHT	4
CROWN ILLUMINATION TREE LD NO DIRECT LIGHT	5
B. WHEN NO TREE LD, WRITE FOR ALL LINE ENTRIES	
LEADING DESIRABLE IS A SAPLING DIPTEROCARP	6
LEADING DESIRABLE IS A SAPLING LISTED SPECIES NON-DIPTEROCARP	7
LEADING DESIRABLE IS A SEEDLING DIPTEROCARP	8
LEADING DESIRABLE IS A SEEDLING LISTED SPECIES NON-DIPTEROCARP	9
THE QUADRAT CONTAINS NO LEADING DESIRABLE	1

SKETCH-MAP OF QUADRAT

COMPASS ORIENTATION OF QUADRAT
CORNER A: DUE WEST – DUE NORTH.
CORNER B: DUE NORTH – DUE EAST.
CORNER C: DUE EAST – DUE SOUTH.
CORNER D: DUE SOUTH – DUE WEST.
THE CORNERS, ABCD, OF ALL QUADRATS IN AN ASSESSMENT PLOT TO BE ORIENTED IN THE SAME DIRECTION.
FOR FIRST ENUMERATIONS, SHOW RESERVED TREES, CUTSTUMPS ALL TREES 10·0+ CMS. DBHOB, LIVING OR WHICH DIED AFTER TREATMENT, TRACTOR TRACKS, WATERCOURSES, FOREST CLASSES & FOREST CLASS BOUNDARIES.
FOR LATER ENUMERATIONS, SHOW NEW RECRUITS AND CORRECTIONS ONLY.

32-33. SILVICULTURAL TREATMENT.	
STEM DEAD BEFORE TREATMENT	10
RESERVED TREE	11
STEM FULLY-GIRDLED	12
STEM PARTLY-GIRDLED	13
STEM NOT TOUCHED BY TREATMENT	14
FELLED AS PART OF SILVICULTURAL TRMT.	15

46. CROWN ILLUMINATION.	
EMERGENT	1
FULL OVERHEAD LIGHT.	2
SOME OVERHEAD LIGHT	3
MOSTLY SIDELIGHT.	4
NO DIRECT LIGHT.	5

47. CROWN FORM.	
COMPLETE CIRCLE	1
IRREGULAR CIRCLE	2
HALF – CIRCLE	3
LESS THAN HALF-CIRCLE	4
ONLY A FEW BRANCHES	5
MAINLY COPPICE	6
ALIVE, BUT NO CROWN	7

48. STEM LEAN.	
ERECT, LEAN LESS THAN 15 DEGREES	1
LEAN, NATURAL INFLUENCES	2
LEAN, NATURAL CAUSES	3
LEAN, DUE TO LOGGING	4
LEAN, DUE TO SILVICULTURAL TREATMENT	5

49. STEM STABILITY.	
STEM APPEARS COMPLETELY STABLE	1
POSSIBLE FALL WITHIN FIVE YEARS	2
CERTAIN FALL WITHIN FIVE YEARS	3

50-53. TREE INJURY.	
NO INJURY EVIDENT	1
DUE TO STORM	2
DUE TO FLORA AND FAUNA	3
LOGGING – HEAVY MACHINERY	4
LOGGING – FELLING ONLY	5
LOGGING – MACHINERY + FELLING	6
CONSEQUENCE OF SILVICULTURAL TREATMENT.	7

54-57. TREE DECAY.	
NO SIGNS OF DECAY	1
PRESENCE OF DECAY SUSPECTED	2
DECAY IS EVIDENT	3

58. LOG GRADE.	
COMMERCIAL NOW (4+ METRES TO 45 CMS)	1
COMMERCIAL IN FUTURE (4+ METRES LONG)	2
NO LOG. STEM DEFORMED	3
NO LOG. STEM DAMAGED	4
NO LOG. STEM DECAYED	5

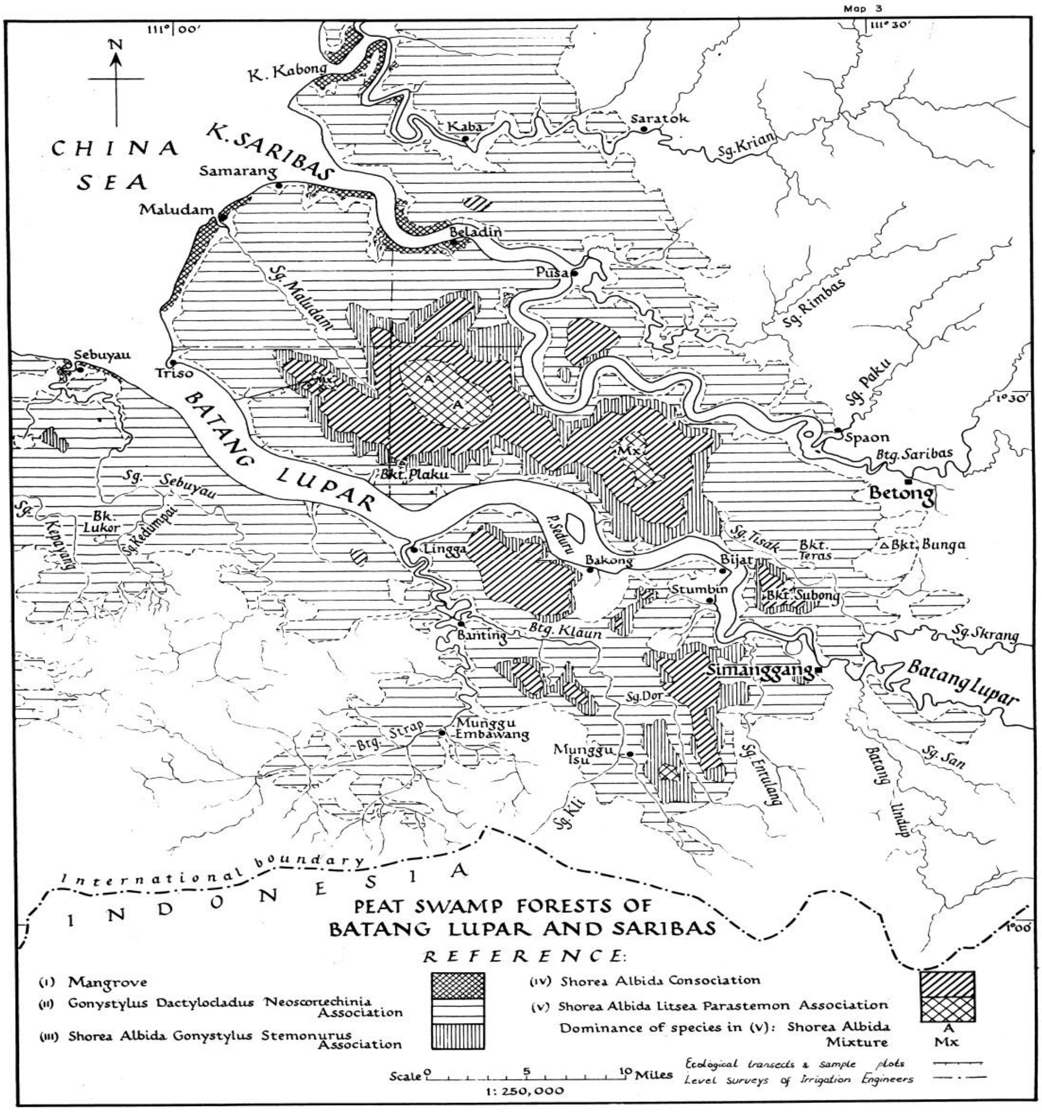
59. WOODY CLIMBERS.	
NONE EVIDENT ON TREE	1
RECENTLY CUT NONE REMAIN ALIVE	2
RECENTLY CUT HARMLESS SPECIES ALIVE	3
HARMLESS CLIMBERS ON TRUNK	4
HARMLESS CLIMBERS ON CROWN	5
HARMLESS CLIMBERS ON TRUNK & CROWN	6
HARMFUL CLIMBERS ON TRUNK	7
HARMFUL CLIMBERS ON CROWN	8
HARMFUL CLIMBERS ON TRUNK & CROWN	9

UNIT AREAS.		
ASSESSMENT PLOT	1·00 OR 0·25	HA
QUADRAT	0·01	HA
SAPLING SUBPLOT	0·0025	HA
SEEDLING SUBPLOT	0·000625	HA

STan.

L—B2/20JPN. Kch

Appendix 3 Map of Maludam peat swamp forest types[8]



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8 After Anderson 1961